DEMONSTRATION OF AN RF-PHOTONIC MICROWAVE CHANNELIZER USING AN OPTICAL FIBER RECIRCULATING LOOP

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ABSTRACT

A new type of RF-photonic channelizer is demonstrated which makes use of a pulse replication loop to realize a true time domain correlation receiver. We have demonstrated, for the first time, a one-step channelization of a total bandwidth of 1.3 GHz and over 400 channels from a single input RF signal pulse. Our channelizer's system architecture is scalable and tunable to a total bandwidth of tens of GHz and over a thousand channels.

1. INTRODUCTION

The army's RF-microwave surveillance, radar and communication systems for signal and signature processing, SIGINT, ELINT, COMINT, etc. are developing with greater demands in regard to high resolution, wide bandwidth and high speed channelizers. Conventional electronic channelizers use RF-filtering circuits which can only provide a few channels to capture and digitize an input signal. Their bandwidth is limited by the speed and effective number of bit (ENOB) of the analog to digital converter (ADC). Therefore the current channelizers cannot detect and channelize a single short multifrequency signal. [1]

We are developing a new type of RF-photonic microwave channelizer[2] that can channelize a single short duration input signal. The concept involves carrying the input RF signal by an optical carrier in a fiber-optic recirculation loop system which can perform a time-domain auto-correlation. After a fast Fourier transformation, we can then obtain the frequency spectrum. Figure 1 shows a basic block diagram of the concept in its simplest form. The RF signal is embedded on two optical carriers by using modulated lasers. Each optical signal is then replicated in a fiber optic loop with

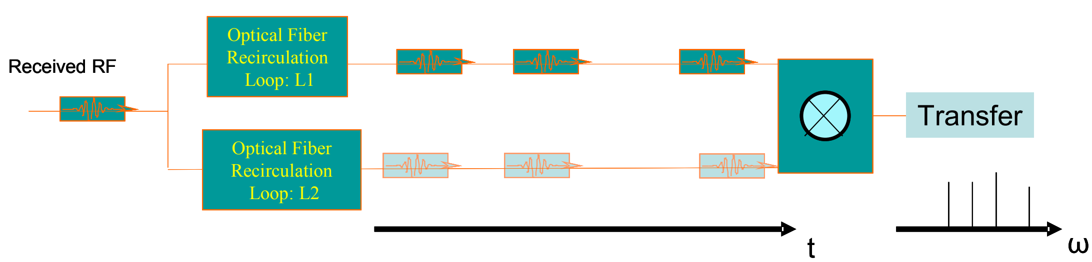

Figure 1. Autocorrelation of RF signal in replicated optical pulses

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effective lengths differing by ΔL. Each pass through the loop introduces a relative phase shift of $2\pi\,\Delta Lf/c$, where f is the RF frequency of any component of the RF pulse and c is the speed of light in the fiber. In this configuration the total bandwidth is ultimately limited by the speed of the optical modulator and detector, and the number of channels is limited to the number of replicas that can accurately be generated. Potentially, this method could be used to create a channelizer with a bandwidth of 50GHz or higher and with thousands of high resolution channels.

2. EXPERIMENT

We have performed a laboratory demonstration of such a system. The set-up is illustrated in figure 2.

RF modulation is applied to a pair of lasers operating in ITU channels in the 1550 nm range. After the signals are combined with a wavelength division multiplexer (WDM), a Mach Zehnder optical modulator is used as a gate switch to catch the RF input signal on a pair 10-18 μs optical carriers (from the two lasers).

The signal-pair is then sent to the fiber optic recirculating loop via a 2x2 fiber optic coupler. We used a single loop of about 10 Km fiber with inclusion of a pair of WDMs within it. The WDM split the optical signals into two paths depending on their wavelengths to create and control the optical path length difference between the two colored pulses in the split section. Since the dispersion of the two colors over the 10 kilometer length of the loop is significant, by adjusting the lengths of the split section in the loop, we can compensate for the intrinsic effective path length change, and introduce the ΔL we desire. The single loop is highly desirable because it allows the signals to experience almost identical histories. Separate loops would mean separate sources of noise and instability which would present significant obstacles to good performance.

Each pass through the loop reduces signal strength due to lossy optical elements, with an additional signal reduction due to the coupling out of a replicated pulse. An Er doped fiber amplifier (EDFA) is used to compensate for this loss. The EDFA introduces several complications. Insufficient amplification will lead to only

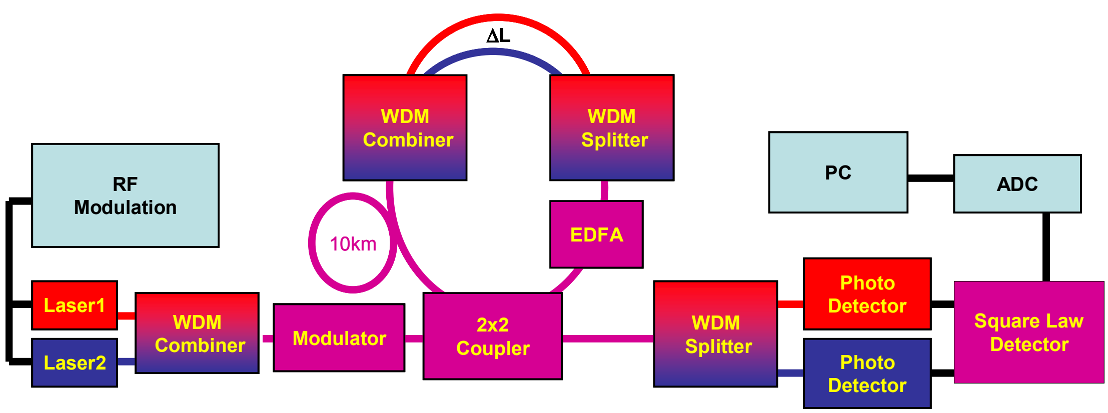

Figure 2 Simplified diagram of channelizer demonstration experimental set-up

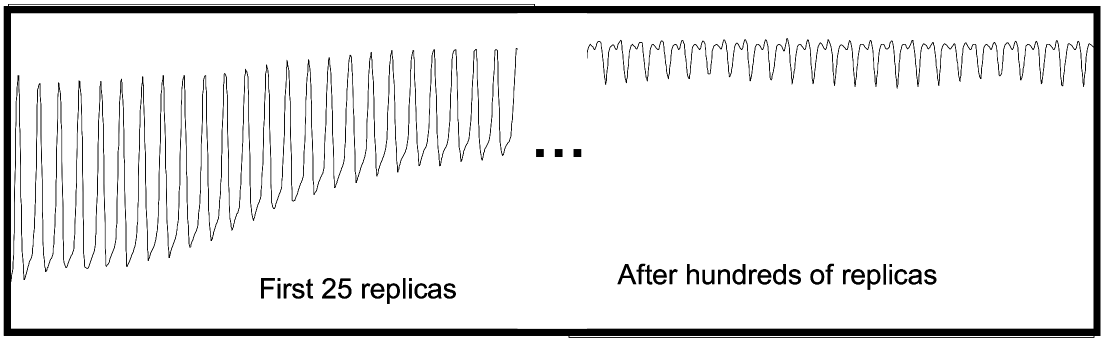

Figure 3. On the left are the first 25 replicated pulses. The noise floor is seen to be rising. On the right are 25 pulses after several hundred replicas. The noise floor is high, and significant distortion has taken place.

few replicas being produced. Excessive amplification can cause the system to resonate, so it essentially function as a ring laser. A limiting amplifier can not be used because it would suppress the embedded RF signal. There is also the problem of the off-state noise being amplified. All EDFAs emit some broad spectrum spontaneous emission noise. That noise, unlike the short duration data, is constantly fed into the loop. For this reason, every effort is made to limit the losses in the loop, and thereby limit the amplification necessary. Figure 3 shows the effect of compounded noise amplification for simple signal replication with a single optical wavelength and no RF modulation. The noise floor rises with each pass, and the pulse shape distorts.

The EDFA does not amplify the signals identically. Over a small number of replications this is trivial, but for hundreds of good quality replicas that are relatively balanced in amplitude, a variable attenuator (not shown) must be placed in one of the arms of the split section of the loop.

Also isolators are used to ensure that no light reflected by other components enters the EDFA from the output port, a well as a polarization rotator. The latter is necessary because each pass through the loop introduces some polarization rotation to which the optical coupler is sensitive. By compensating with the rotator, we ensure that each replica is coupled out in a consistent manner.

Upon exiting the loop, the two optical wavelengths are split by a WDM and sent to photodectors, returning the signal to the RF domain. Each pair of replicas has a time delay of $n\Delta L/c$, where n is the number of the replica. This time delay corresponds to some phase difference for the component frequencies that make up the RF signal. The paired replicas are combined and beat with a square law detector, the output of which is band pass filtered, sent to an ADC where the low frequency components are correlated and digitized. A fast Fourier transform (FFT) is performed on the time domain data, converting it to the frequency domain.

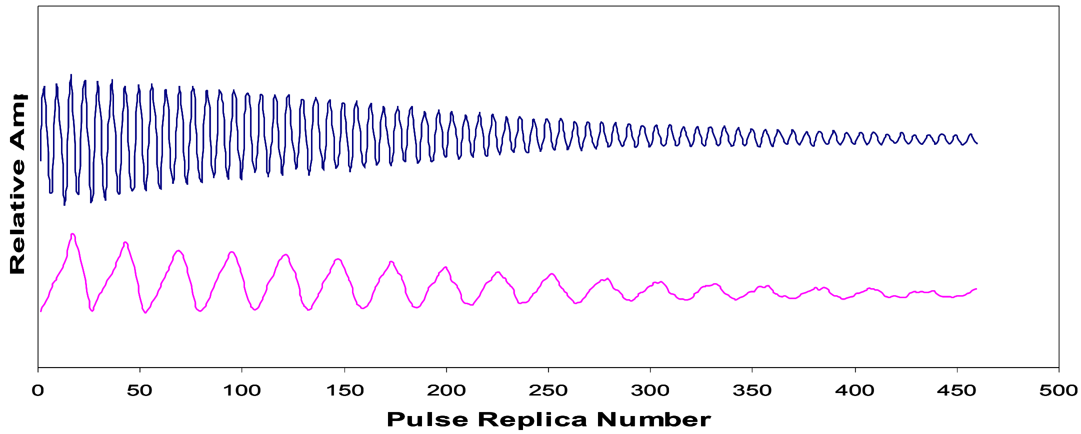

Figure 4. Relative amplitude of correlated pulse pairs for 100 MHz (lower) and 400 MHz (upper) RF modulation. The 400 MHz signal is not stronger (absolute magnitude is not important), they are merely separated for clarity.

3. DATA AND ANALYSIS

To test our experimental system, we used an RF signal synthesizer to create single frequency inputs of 200, 400, 800 and 1200 MHz. An effective ΔL of 11cm, a loop of 11.1 km (37 μs transit time) and a pulse duration of 18 μ s was made by the optical modulator/switch. Since more than π phase shift in a single pass through the loop would cause ambiguity in the data analysis, this limits our bandwidth to c/ $2\Delta L$, or 1.3 GHz. Reducing Δ L to 3 mm would allow over 40 GHz bandwidth. We modulated both lasers by the CW RF frequencies of 100, 200, 400, 800, and 1200 MHz. Because the modulator and other components in the system were not perfectly linear, we expect to see some harmonic frequencies to be propagated along with the fundamental. We were able to correlate and digitize as many as 450 replicated pulse pairs. This is well below the theoretical limit. At most, we could introduce 18 μs of relative time delay between the pulses, at which point they would not overlap. This would be about 50000 replicas. The practical limit is well below this, though our pulse replica quality does not yet allow us to approach that number. Figure 4 shows the relative amplitude of each pulse-pair correlation for frequencies of 100 MHz and 400 MHz. The sinusoidal component is obvious. The amplitude reduction is due primarily to the rising noise floor of the raw pulse replication data.

Figure 5 shows the results of fast Fourier transforms on the 200, 400, 800 and 1200 MHz data. The peaks for the fundamental frequencies are clear and well defined. As expected, due to the nonlinearity of the RF modulation, peaks are present for harmonic frequencies for the lower frequency data. For the higher frequency data, they are out of band.

Because the data was taken over 450 replicas, the implication is that there should be 450 output channels over the 1.3 GHz bandwidth. There may be complications due to the reduced signal to noise ratios of the later pulses. Because of noise, each channel might introduce

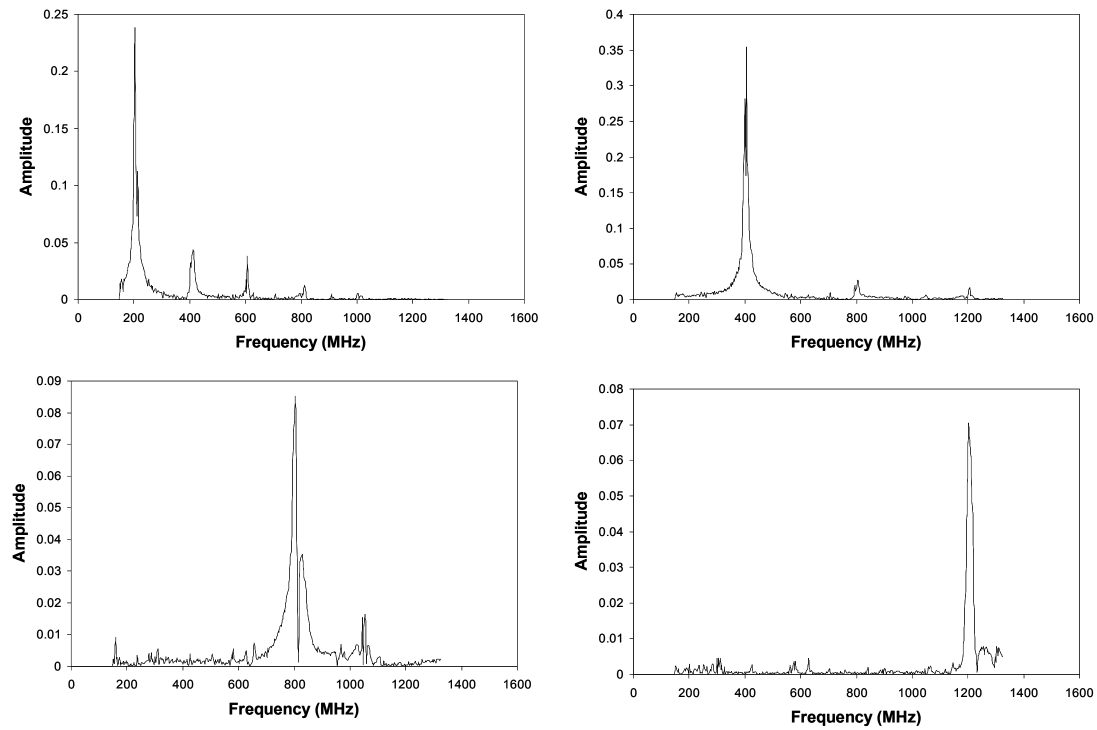

Figure 5. Fourier transformed data for 200, 400, 800 and 1200 MHz. The clear spikes of the fundamental frequencies are obvious, and the small spikes of the harmonics are visible for the lower frequencies.

spurious signal in adjacent channels. Effectively, the full width at half maximum resolution extends to approximately 10-14 MHz, reducing the number of channels by a factor of about 5 to 90 effective channels.

4. CONCLUSION

In conclusion, we have experimentally demonstrated a new concept for RF channelizing by novel RF-photonic time domain auto-correlation architecture. This channelizer can detect and channelize a single short RF pulse and is scalable to thousands of channels and many tens of GHz bandwidth. This represents a significant improvement over existing technology. Such improvement can have significant impact on a broad array of Army tasks involving RF signal detection and processing.

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